Alberta
ENVIRONMENT

PROGRESS REPORT
"THE EFFECTS OF WELL CASING MATERIALS ON GROUNDWATER CHEMISTRY"

ALBERTA ENVIRONMENT

ENVIRONMENTAL PROTECTION SERVICES

EARTH SCIENCES DIVISION

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ABSTRACT

The effects of different well casing materials on groundwater chemistry were studied by using six wells constructed with two different types of well casing material at three sites. These six wells include two wells at each site, one constructed with steel casing and the other with PVC casing. Groundwater samples were obtained on a once per month and analysed for routine chemical constituents, COD and heavy/trace elements. EC and pH were also measured on-site at the time of sampling.

The results indicate that steel casing, in contact with well water for a month between sampling intervals, caused significant changes in pH and in concentrations of a few chemical constituents. The changes, especially for the alkaline earth metals, appear to be site specific, depending on the chemical characteristics of the groundwater at the site. When groundwater samples were collected after flushing four well volumes of water, there was no significant difference in the water chemistry between samples from wells cased with the two different types of material. More work however will be required to finally verify these preliminary results.

In future studies, emphasis needs to be directed to the organic constituents of groundwater. It would also be desirable to determine whether microorganisms influence the uptake and release of any of the chemical constituents.

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INTRODUCTION

The quality of groundwater for the Provincial Observation Well Network is routinely determined by obtaining samples from an established system of monitoring wells. These wells are frequently constructed with steel or polyvinyl chloride (PVC) casing. However, under field conditions, the adsorption and leaching characteristics of organic and inorganic chemical constituents with these standard well casing materials have been given little attention.

Relatively small amounts of adsorption or leaching can greatly affect sensitive analytical results, when determining trace levels of chemical constituents. For example, PVC adhesive, which is used to join sections of casing and screen, may contain such compounds as tetrahydrofuran (THF) and methylethyl ketone (MEK) as major constituents (Sosebee, 1982), and PVC well casing contains significant amounts of zinc, iron, antimony and copper (Robertson, 1968a). These organics and metals, on contact with well water, may be leached from the casing into the groundwater. Certain trace elements, especially iron, indium, scandium and silver, have been adsorbed in significant quantities on container surfaces, when stored in glass and polyethylene bottles (Robertson, 1968a; 1968b).

The primary objectives of this study are (1) to identify chemicals that may leach from well casing materials when exposed to groundwaters of different quality, (2) to identify chemical constituents of groundwater that may be adsorbed on various well casing materials and (3) to provide guidelines for material selection and data interpretation during groundwater monitoring.

As a trial study, steel and PVC well casing materials were studied for their effect on inorganic chemical constituents. This study was initiated in November 1984 by drilling two wells cased with steel and PVC at a site near Ministik Lake. Later, in March 1985, two wells were installed with steel and PVC casings at both Bruderheim and the

Devonian Botanic Garden. In this progress report, the results of the study are discussed and future direction for this study is recommended.

BACKGROUND
(A LITERATURE REVIEW)

Studies have been conducted on the adsorption of metals in various types of containers during storage or preservation of water samples. Robertson (1968a; 1968b) investigated the adsorption of trace amounts of 11 elements from sea water on various containers. Robertson (1968b) indicated that certain trace elements are significantly adsorbed on container surfaces when stored in glass and polyethylene. This adsorption can be prevented by adjusting the pH to 1.5 with hydrochloric acid. Shendrikar, et al. (1976) studied the adsorption characteristics of barium, beryllium, cadmium, manganese, lead and zinc on pyrex, flint glass and polyethyene surfaces during storage under different conditions. They concluded that the method of preservation of water samples recommended by EPA (1979b) was satisfactory.

Struempler (1973) found that a borosilicate glass surface adsorbed Ag, Pb, Cd and Zn, while a polyethylene container did not adsorb Cd or Zn. Struempler (1973) also found that a polypropylene container surface adsorbed all elements studied but, once adsorbed, Cd and Zn were not desorbed satisfactorily. Adsorption of all other elements can be prevented by acidification of the solution to pH 2 with nitric acid (HNO_3). Eichnolz et al. (1965) indicated that borosilicate glassware is preferable over polypropylene to minimize container ion adsorption for the storage of most metals. Robertson (1968a) noted that significant amounts of zinc, iron, antimony and copper may be contained in polyvinyl chloride (PVC) well casing and that polyethylene contains antimony. These metals potentially may leach from these materials and contaminate contacting water.

The adsorption and leaching characteristics of organics with various containers and potential well casing materials have been studied to a much lesser extent than inorganics. A systematic study of the adsorption and desorption of volatile organics, such as trichloroethylene, 1,1,1-trichloro-ethane and bromoform and the metals onto three types of well casing materials (polyethylene, polypropylene and schedule 40 PVC) was conducted recently by Miller (1982). He concluded that schedule 40 PVC causes fewer monitoring interferences with volatile organics than polyethylene or polypropylene, under the laboratory conditions of his experiments. One study on the interaction of m-cresol with two types of plastic tubing has been reported by the U.S. EPA (1980). Industrial grade PVC tubing and bev-a-line VHT tubing were exposed to the m-cresol solution for varying lengths of time up to two hours. The m-cresol was progressively lost to the PVC tubing in amounts proportional to the increasing contact time, while there was no measurable loss of m-cresol to the VHT tubing.

Junk, et al (1974) determined that organic contamination, ranging from 1 µg/L to 5 mg/L by weight, was detected in organic free water which had flowed through tubes of polyethylene, polypropylene, black latex, six formulations of PVC and a plastic garden hose. Among the contaminants found from PVC were o-cresol, napthalene, butyloctylfumarate and butylchloroacetate. The amount of plasticizers in PVC tubing is approximately 40% by weight and represents an essentially inexhaustible supply of contamination. However, in the case of relatively rigid polyethylene and polypropylene tubes, Junk et al. (1974) found that they may eventually become noncontaminating.

Curran and Tomson (1983) passed organic free water through five types of plastic tubing. These included polypropylene, polyethylene, Teflon, Tygon, PVC with glue and PVC without glue. Their results indicate low levels of leachate from all the tubing tested except Teflon, where no leachates were found. Between one and five contaminants, all at concentrations less than 0.5 mg/L, were found

leached into the water from nonglued PVC, polyethylene and polypropylene.
Numerous contaminants were found leached from glued PVC and Tygon. Two organics, napthalene and para-dichlorobenzene, were not adsorbed significantly by any of the tubing except Tygon.

Leaching of organic and organotin compounds from PVC and chlorinated PVC (CPVC) pipes has been studied by Boettner, et al. (1981). They found that alkyltin species and components of organic solvent for pipe cementing can leach into potable water. For example, they found from 10 µg/L to 10 mg/L of MEK, THF and cyclohexanone, from the solvent, leached into the water in a miniature pipe loop exposed for 14 days. Dimethyltin (as dichloride) was found to be leached from the PVC pipe at a concentration of 45 ppb after one day of exposure at 37°C. During 21 additional days of exposure the concentration of dimethyltin decreased, in a diphasic manner, from 3.0 to 0.25 µg/L per day. Lesser levels of dibutyltin were leached from CPVC.

A recent field and laboratory study by Sosebee, et al. (1982) included assessment of the potential for contamination of groundwater samples by six PVC primers and one PVC adhesive. THF, MEK, methylisobutylketone (MIBK) and cyclohexanone were found to be leached into the water surrounding bonded joints. Even though a well was developed after installation and bailed prior to sampling, they found detectable levels of these compounds in well water several months after installation. Up to 110 mg/L of MEK was found after five days of soaking freshly cemented PVC pipe in water. After five washings and a 24-hour equilibrium, the concentration of MEK was reduced to about 0.54 mg/L. Similar trends were noted for the other three contaminants studied, although the presence of each constituent and their relative concentrations varied significantly between solvent brands and manufacturers. All four compounds could be introduced into monitoring wells by one or more of the brands of adhesive. With successive washes with deionized water, concentrations of contaminants declined significantly from a mean total concentration of 77,800 µg/L, after

five days of soaking, to a mean total of 591 µg/L after being washed four more times with deionized water and soaked for an additional 24 hours.

Field sampling with a PVC bailer, constructed several weeks before, resulted in samples with low levels of THF and MEK. Using a PVC bailer constructed 30 minutes prior to sampling, Sosebee, et al. (1982) found 16 mg/L cyclohexanone, 3.8 mg/L MEK and 1.4 mg/L THF in a groundwater sample. Contaminants in PVC solvents can mask the presence of other volatile priority pollutants that elute from the chromatograph at similar retention times. For example, MEK and 1,2-dichloroethane, cyclohexannone and bromoform, and THF and 1,1-dichloroethane all coelute with the EPA analytical protocol.

While PVC is the most common type of synthetic well casing material in use, other materials have been used or could be used including, for example, acrylonitrile butadiene styrene (ABS), styrene-rubber (SR), polyethylene, polypropylene, Teflon and Kynar. The state of knowledge of the potential effects of well construction, and pump and sampling materials on the integrity of groundwater samples is extensively reviewed by Barcelona et al. (1983).

PettyJohn, et al. (1981) indicated in a recent article that, when sampling organic contaminants, the preferred order of choice of well casing materials and materials for sampling devices includes glass, Teflon, stainless steel, polypropylene, polyethylene, other plastics and metals and rubber. They also indicated that detailed experimental data on material selection are simply not available.

MATERIALS AND METHODS

SITE SELECTION

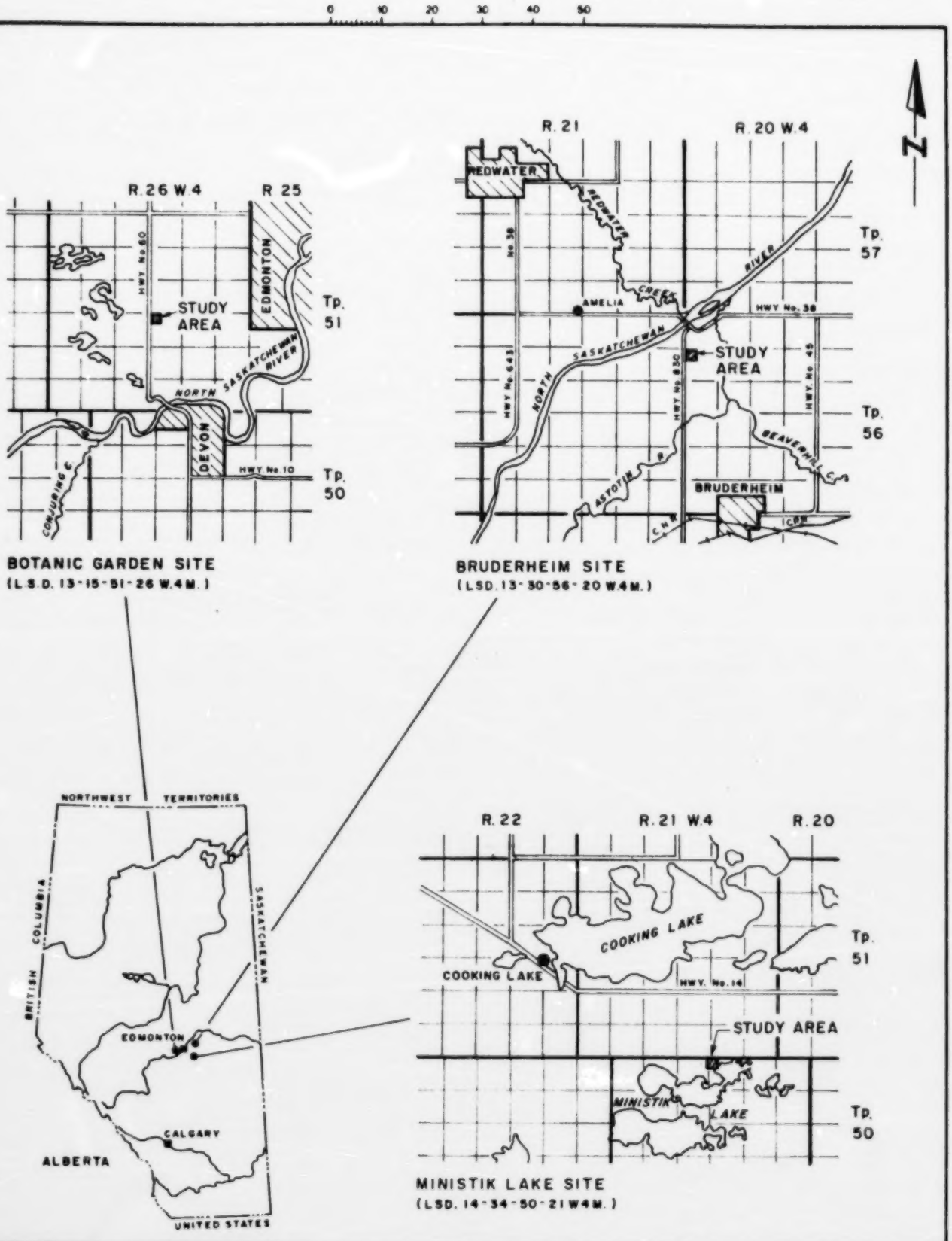
Monitoring wells at three sites (Ministik Lake, LSD14-34-50-21-W4; Bruderheim, LSD13-30-56-20-W4; Devonian Botanic Garden, LSD13-15-51-26-W4) within the Edmonton map area (NTS 83H) have

been selected (Figure 1). These sites represent a cross section of hydrogeologic conditions and chemical characteristics of aquifer water.

At each site, two wells were installed in a similar manner but with different well casing materials (PVC and steel casings). At the Ministik Lake site, wells (#2322E and #2323E) were completed in a coal seam aquifer in the Upper Cretaceous Horseshoe Canyon Formation. Wells #2342E and #2343E at the Bruderheim site were installed in an aeolian sand dune aquifer. At the Botanic Garden site, two wells (#2329E and #2330E) were constructed in the glaciolacustrine sand aquifer (Botanic Garden #1). Monitoring of the latter two wells was terminated after four months because water samples were dirty, due to well screen damage. Later, an additional well (#2369E) was installed in a similar manner to an existing well (#2328E) at the site (Botanic Garden #2), but using PVC casing. These two wells, (#2328E and #2369E) which are used as replacements for the previous wells (#2329E and #2330E), were completed in the preglacial sand aquifer. Hydrogeology of the study areas, well construction and aquifer test results are described in detail in Appendix B. Selected information for the wells at the three sites is summarized in Table 1.

PUMPING EQUIPMENT

A peristaltic and submersible pump were selected for collecting samples from wells at the study sites. For wells at Ministik Lake, Bruderheim and Botanic Garden #1, where pumping lifts were within suction lift capabilities, a Masterflex 7545 variable speed drive unit, equipped with a 7015 peristaltic pump head, was used to collect the initial water in storage designated as "before well flushing". For wells at the Botanic Garden #2, where pumping lifts were beyond suction lift capabilities, a submersible pump was used to collect the initial water sample. The same submersible pump was used to collect water samples after four well volumes were pumped to flush wells at the



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SUBMITTED Y.M. Chae DATE 1987/12/18	DESIGNED Y. M. CHAE CHECKED	LOCATION PLAN
APPROVED R. Hamilton DATE 9 Dec 1987	DRAWN H.O. CHECKED	SCALE —— SHEET OF DATE 1986 NOV FIGURE No. 1

Table 1. Well construction and aquifer details.

Site	Well Casing Material (Well Number)	Total Well Depth m	Depth to Water Level m	Production Interval m	Yield L/sec	Aquifer Lithology
Ministik	Steel (#2322E)	49.4	4.82	47.9-49.4	2.1	coal
	PVC (#2323E)	49.4	4.95	47.9-49.4	2.1	coal
Bruderheim	Steel (#2342E)	10.0	5.94	8.5-10.0	-	sand
	PVC (#2343E)	10.0	6.01	8.5-10.0	-	sand
Botanic Garden #1	Steel (#2329E)	10.6	2.07	9.1-10.6	0.04	sand
	PVC (#2330E)	10.6	2.12	9.1-10.6	0.04	sand
Botanic Garden #2	Steel (#2328E)	47.5	20.31	46.0-47.5	5.0	sand
	PVC (#2369E)	47.5	19.74	46.0-47.5	5.0	sand

Bruderheim and Botanic Garden #1 and #2 sites. The water samples collected after well flushing were designated as "after well flushing".

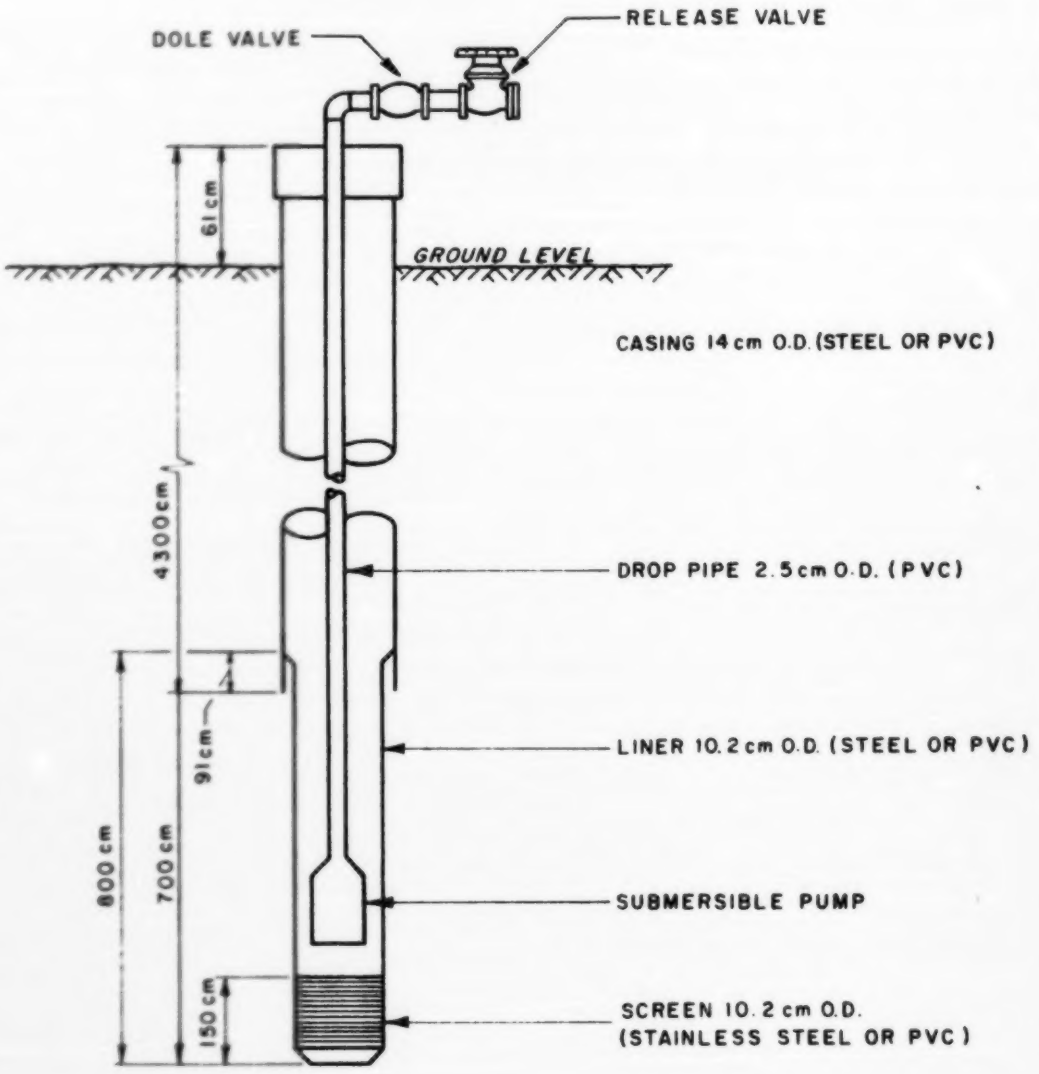
An apparatus, similar to that shown in Figures 2 and 3, was used with a submersible pump dedicated to each well for the wells at the Ministik Lake site. Water samples designated as "after flushing" were collected with the dedicated pumps after four well volumes were flushed using the peristaltic pump.

The Masterflex pump is capable of producing from approximately 50 to 1000 mL/min (0.013 to 0.264 igpm), when operated on internal batteries. The flow rate from the submersible pump is controlled by a dole valve. The submersible pumps used are 73.7 cm (29 in.) long, 9.8 cm (3.875 in.) in diameter, and delivered water from 45.7 m (150 ft.) at a rate of 18.9 L/min (5 gpm).

SAMPLE COLLECTION AND PREPARATION

Wells at each of the three sites were sampled once a month using the pumping systems and procedure described in the previous section. To date, fourteen and eight sets of samples have been collected and analyzed from the Ministik Lake and Bruderheim sites, respectively. Only four sets of samples from each of Botanic Garden wells #1 and #2 have been collected and analyzed, due to the well screen damage at site #1 and subsequent construction of an additional well at site #2 in October 1985.

In an earlier part of this study a series of groundwater samples were collected during a five hour pumping period, in order to determine the number of well volumes which must be removed before obtaining a representative sample. One well volume is defined as the amount of water occupying the well casing before pumping is initiated. Samples were taken at zero, 0.5, 1, 2, 4, 6, 8 and 10 well volume pumped intervals. In this earlier study, it was found that a representative sample was obtained after removing four well volumes. Subsequently



NOTE: WELL CONSTRUCTION DETAIL AND PUMPING MECHANISM AT THE MINISTIK LAKE SITE.

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SUBMITTED Y.M. Chae DATE 1987/12/18	DESIGNED Y.M. CHAE CHECKED	WELL CONSTRUCTION DETAIL
APPROVED R. Hamilton DATE 9 Dec 1987	DRAWN M.O. CHECKED	SCALE —— SHEET OF
		DATE 1986 NOV. FIGURE No. 2

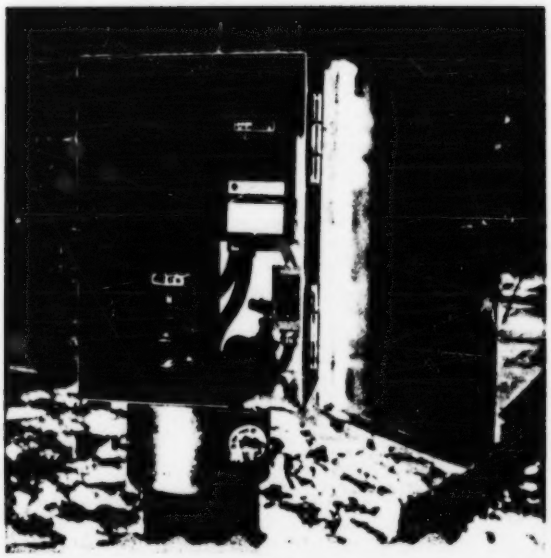


Figure 3. The pump house set on the top of well casing at the Ministik Lake

samples were taken from the initial water in storage, designated as "before flushing", and at the four well volume interval designed as "after flushing".

Measurements of pH, specific conductance, and alkalinity were made on-site from unfiltered aliquots of each of the well volumes or partial well volumes that were sampled. The on-site measurements were conducted immediately after the aliquots were collected, to minimize changes in chemical composition due to exposure to the atmosphere. Samples for routine, metals and chemical oxygen demand COD) analyses were also collected, preserved and transported to the laboratory.

The sample aliquots were subdivided into four portions. Two aliquots for trace/heavy metals were acidified with nitric acid to a pH of 2.0, one taken before filtering and the other immediately after filtration with 0.45 μm pore size membranes. The aliquot for COD was preserved by the addition of 2 ml of 50% (v/v) sulphuric acid. The aliquot for routine analyses was not preserved. Aliquots for all analyses were contained in linear polyethylene bottles and stored in a refrigerator. Detailed procedures used for sample preservation in this study are given by the U.S. EPA (1979a; 1979b).

All samples were analysed by the Soils Protection Branch in Lethbridge. Field measurement of pH was conducted with an Orion 407A field model pH meter. Specific electrical conductance (EC) was measured with a YSI model 33 S-C-T meter.

RESULTS AND DISCUSSION

The chemical data for water samples collected from the wells at the study sites are shown in Tables A1-A8 in Appendix A. All values in these tables are mean values of 14, eight and four sets of samples collected from the Ministik Lake, Bruderheim and Botanic Garden #1 and #2, respectively. Analysis of variance was carried out for the data

and results of the statistical analysis are shown in Tables A1-A8.

The data from these statistical analyses are being evaluated in an effort to explain the variations in chemical concentrations with different well casing materials. In addition, data were also collected to determine the effects of well flushing, sample preparation and storage on chemical compositions of groundwater from wells of different well casing materials. In this progress report, however, discussion will be limited to the effects of well casing materials on the chemical compositions of the collected groundwater samples.

In general, chemists attribute pH as the single most important factor affecting the chemistry of groundwater. Therefore, contributors that alter the pH of groundwater samples may alter the chemistry of its constituents. For this reason, on-site pH measurements were carried out during the sampling period at all three sites. Results of pH measurements on-site and in the laboratory are summarized in Table 2.

The analysis of variance showed that there was no statistically significant difference between pH values measured on samples collected before and after well flushing, regardless of measurement time (i.e., in the field or in the laboratory) except for the well with steel casing at the Ministik Lake site. For the Botanic Garden #2 site, pH values measured in the laboratory were always significantly higher than the values measured in the field, regardless of the type of well casing material and amount of well flushing. The latter difference in pH was probably due to stripping of dissolved CO_2 in excess of atmospheric pressure during both the storage period in the well casing and sample storage prior to being analysed.

In addition, the pH values measured before well flushing were higher than the values measured after well flushing for most samples from steel cased wells. However, for PVC cased wells, the pH values measured after well flushing were always equal to or higher than the values measured before well flushing. Although the difference in pH

Table 2. Effects of well casing materials on pH measured in the field and in the laboratory.

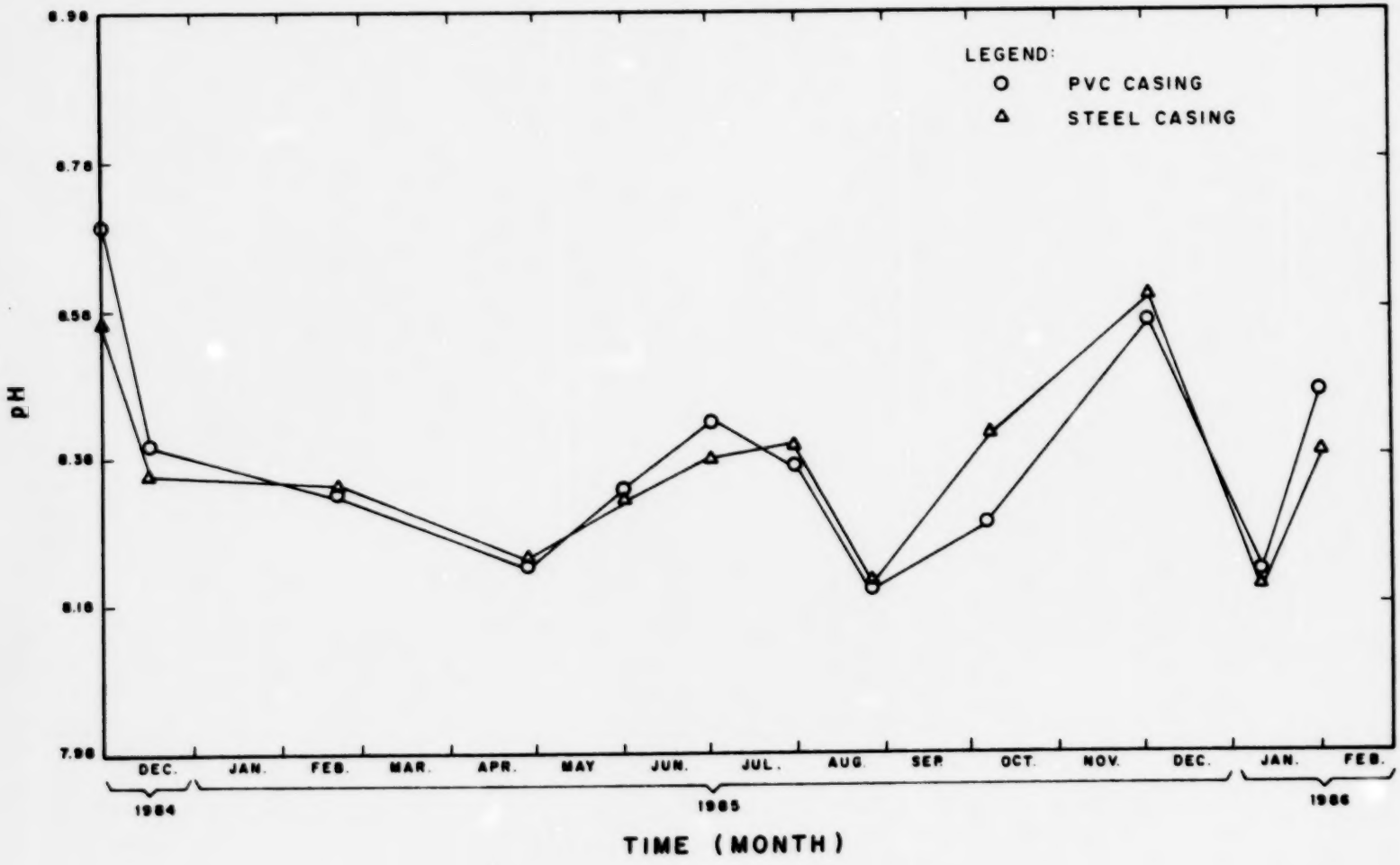
Site	Before Pumping		After Pumping	
	Steel	PVC	Steel	PVC
Ministik Lake				
Laboratory	8.89[a]	8.29[b]	8.36[b]	8.38[b]
Field	8.76[a]	7.98[b]	7.91[b]	7.98[b]
Bruderheim				
Laboratory	7.59	7.33	7.41	7.35
Field	7.50	7.16	7.14	7.28
Botanic Garden #1				
Laboratory	7.67	7.12	7.89	7.54
Field	7.48	6.70	6.98	7.26
Botanic Garden #2				
Laboratory	7.86[a]	7.74[a]	7.93[a]	7.82[a]
Field	7.23[b]	7.15[b]	7.09[b]	7.15[b]

Note: 1. Numbers are mean values in pH unit.
2. Within each sampling site, numbers without superscripts (a and b) or numbers with the same superscripts were not significantly different at $P < 0.001$.

trends between the two well casing materials was not supported by a statistical analysis, this difference could be a useful means to understand the chemical reactions occurring in wells cased with different materials.

Seasonal fluctuations of pH at the Ministik Lake site are shown in Figure 4. The values in this plot are those measured in the laboratory on the samples collected after well flushing. The pH values of December samples were the highest and those of August were the lowest. The difference in pH between these two extremes was approximately 0.5 pH unit. This difference, which is the amplitude of seasonal variation, is considerably higher compared with the differences in mean values between the field and laboratory measurements (ranging 0.09 - 0.91 unit) and between mean values for different well casing materials (ranging 0.01-0.78 unit) as shown in Table 2. The high amplitude value is probably one reason why analysis of variance did not show statistically significant differences between samples collected before and after flushing, except for the Ministik Lake site (Table 2). For this reason, all other sites need to be monitored at least one full year.

Some chemical constituents, which show statistically significant ($P<0.05$) difference between the two casing materials, are summarized in Table 3 and 4. Concentrations of Ca and COD in samples collected from steel cased wells are significantly different depending on the measurement time (Table 3). In most instances involving steel casings, Ca contents in the samples collected after well flushing were significantly higher than those for the samples collected before well flushing. However, concentrations of COD, for samples collected from steel cased wells before well flushing, were significantly higher than those in the samples collected after well flushing. There were no significant differences in the concentrations of Ca and COD for the samples collected from the PVC cased wells, regardless of well flushing.



NOTE: SEASONAL VARIATIONS OF pH AT THE MINISTIK LAKE SITE.

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SUBMITTED Yim Chae	DESIGNED Y. M. CHAE	SEASONAL VARIATIONS OF pH
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APPROVED R Hamblin	DRAWN N.O.	SCALE —— SHEET OF
DATE 9 Dec 1987	CHECKED /	DATE 1986 NOV. FIGURE No. 4

Table 3. Effects of well casing materials on some selected chemical constituents of groundwater.

Site	Chemical Constituents	Before Pumping		After Pumping	
		Steel	P.V.C.	Steel	P.V.C.
Ministik Lake	Ca	2.51[a]	5.34[b]	4.17[b]	4.93[b]
	HCO_3	1186[a]	1349[b]	1326[b]	1321[b]
	SO_4	17.21[a]	10.45[b]	17.93[a]	9.93[b]
	COD	50.64[a]	34.55[b]	27.67[b]	29.18[b]
	TDS	1220	1238	1236	1226
Bruderheim	Ca	61.62[a]	80.02[b]	92.06[b]	86.02[b]
	HCO_3	278.4	300.2	346.0	337.5
	SO_4	19.45	17.84	18.61	18.41
	COD	21.40[a]	15.17[ab]	10.00[b]	13.75[ab]
	TDS	254.9	268.3	308.7	292.7
Botanic Garden #1	Ca	76.90[a]	88.43[ab]	150.3[b]	142.5[b]
	HCO_3	710.9	634.6	1178	1135
	SO_4	169.9	100.9	146.5	162.5
	COD	61.50[a]	155.0[b]	140.0[b]	193.7[b]
	TDS	833.4	658.7	1170	1158
Botanic Garden #2	Ca	156.5[a]	62.46[b]	68.64[b]	65.13[b]
	HCO_3	850.6	863.6	846.7	872.1
	SO_4	518.7[a]	200.9[b]	197.6[b]	199.7[b]
	COD	67.50[a]	27.50[b]	25.25[b]	18.00[b]
	TDS	1448[a]	1018[b]	993.4[c]	1026[b]

Note: 1. Concentrations of all chemical constituents are mean values in mg/L.
2. Within each sampling site, numbers without superscripts (a, b, c, etc.) or numbers with the same superscripts were not significantly different at $P < 0.05$.

Table 4. Effects of well casing materials on some selected metals in groundwater.

Site	Metal	Before Pumping		After Pumping	
		Steel	P.V.C.	Steel	P.V.C.
Ministik Lake	Ba	0.065[a]	0.167[b]	0.167[b]	0.163[b]
	Fe	0.815[a]	0.291[b]	0.228[b]	0.127[c]
	Mn	0.026[a]	0.012[b]	0.010[b]	0.012[b]
	Sr	0.071[a]	0.098[b]	0.102[b]	0.102[b]
Bruderheim	Ba	0.521[a]	0.675[b]	0.814[b]	0.766[b]
	Fe	5.143	4.056	4.937	5.060
	Mn	0.381	0.510	0.459	0.433
	Sr	0.273	0.202	0.260	0.260
Botanic Garden #1	Ba	0.093	0.078	0.150	0.167
	Fe	9.095	5.588	9.900	10.167
	Mn	0.148	0.108	0.100	0.270
	Sr	0.768	0.823	1.270	1.240
Botanic Garden #2	Ba	0.080	0.060	0.054	0.052
	Fe	17.600[a]	1.483[b]	4.960[c]	3.080[d]
	Mn	0.698[a]	0.757[b]	0.617[c]	0.758[b]
	Sr	1.630[a]	-	0.965[b]	-

Note: 1. Concentrations of all metals are mean values determined on acidified samples, and expressed in mg/L.

2. Within each sampling site, numbers without superscripts (a,b,c,etc.) or numbers with the same superscripts were not significantly different at $P < 0.05$.

As shown in Table 3 & 4, the steel cased wells in deeper aquifers (i.e., Ministik Lake and Botanic Garden #2 sites) appear to have affected concentrations of Fe, Mn and the alkaline earth metals Ba, Ca, and Sr. Any changes in pH are likely to affect the concentrations of metals as well as other chemical constituents. However, it is interesting to note that the effects of well flushing on pH and the concentrations of the alkaline earth metals for the samples from the steel cased well at the Ministik Lake site are opposite to the effects for the same metals from the steel cased well at the Botanic Garden #2. For example, at the Ministik Lake site the concentrations of Ba, Ca and Sr, for the samples collected after well flushing, were significantly higher than those for the samples collected before well flushing. On the other hand, the Ba, Ca, Sr concentrations for samples collected after well flushing were lower than those collected before well flushing at the Botanic Garden #2 site. These different effects possibly indicate that, during the storage period between sampling intervals, any changes in the concentrations of the chemical constituents of groundwater in a well occur under different reaction mechanisms and kinetics depending on the chemical characteristics of the aquifer water.

Perhaps the most significant finding of this study is the fact that pH and the concentrations of most inorganic constituents of groundwater studied were not affected by the type of well casing materials studied, if analyses were done on the samples collected after flushing four well volumes of water.

CONCLUSIONS AND FUTURE DIRECTIONS

This study examined two types of well casing materials exposed to four different groundwater regimes under field conditions. It was found that the steel casing, when in contact with well water during one month intervals between samplings, caused some changes in pH and concentrations of a few chemical constituents (COD, SO_4, Cl, Ca, Ba, Sr, Fe and Mn). The PVC casing did not cause any significant changes during the same sampling intervals, with the exception of the Fe concentration. However, there was no significant difference in the concentrations of most chemical constituents when samples were collected after flushing, regardless of the type of well casing materials. These results suggest that well flushing before sample collection is one of the most important protocols for collecting representative groundwater samples.

It was also found that the concentrations of the alkaline earth metals (Ba, Ca and Sr), in the steel cased well at the Ministik Lake site before pumping, decreased during the one month period between sampling, whereas the concentrations in the steel cased well at the Botanic Garden #2 site increased during the same period. In addition, the pH value at the Ministik Lake site increased, whereas the value at the Botanic Garden #2 site decreased. These results indicate that the intensity (quantity) and direction (increase or decrease) of the chemical changes during the contact time with well casing depend on the initial chemical characteristics of the groundwater.

The results of the study to date suggest several interesting questions for future research. During the next year, the effects of the contact duration (casing materials with well water) on the intensity and direction of changes in pH and the chemical concentrations will be examined. The latter study will be carried out by varying the sampling intensively, i.e., once a day for a week, once every other day for a week, once every third day for two weeks, once a week for three weeks, etc. This study will identify how fast the groundwater will degrade in the well.

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APPENDIX A

DETAILS OF CHEMICAL ANALYSES FOR GROUNDWATER SAMPLES

TABLE A1. Routine analysis for wells at Ministik Lake site.

Parameter	Casing Material	Before Flushing	After Flushing
pH	Steel	8.89[a]	8.37[b]
	P.V.C.	8.28[b]	8.38[b]
EC	Steel	1.94	1.94
	P.V.C.	1.95	1.92
SAR	Steel	93.09[a]	68.06[b]
	P.V.C.	61.29[b]	67.17[b]
Ca	Steel	2.51[a]	4.17[b]
	P.V.C.	5.34[b]	4.93[b]
Mg	Steel	0.86	0.76
	P.V.C.	0.66	0.71
T.H.	Steel	9.79	13.54
	P.V.C.	15.83	15.21
Na	Steel	514.43	517.88
	P.V.C.	519.23	513.86
K	Steel	2.31	2.38
	P.V.C.	2.38	2.31
CO_3	Steel	72.30[a]	12.55[b]
	P.V.C.	6.82[b]	13.97[b]
HCO_3	Steel	1186.03[a]	1325.82[b]
	P.V.C.	1349.30[b]	1321.18[b]
T.A.	Steel	1092.56	1108.00
	P.V.C.	1117.76	1106.57
F	Steel	0.56	0.58
	P.V.C.	0.58	0.57
SO_4	Steel	17.21[a]	17.93[a]
	P.V.C.	10.45[b]	9.93[b]
Cl	Steel	27.47[a]	27.99[a]
	P.V.C.	29.76[b]	29.83[b]
NO_3-N	Steel	0.07	0.07
	P.V.C.	0.07	0.07

... cont'd.

Table A1. (cont'd.)

Parameter	Casing Material	Before Flushing	After Flushing
NH_4-N	Steel	0.65	0.75
	P.V.C.	0.48	0.61
COD	Steel	50.64^{a}	27.67^{b}
	P.V.C.	34.55^{b}	29.18^{b}
TDS	Steel	1220.38	1235.97
	P.V.C.	1238.53	1225.56

Note: 1. Numbers are mean values of concentrations (mg/L) determined during the period, December 1984 - February 1986.

2. Within each parameter group numbers without superscripts (a,b,c,etc.) or numbers with the same superscripts were not significantly different at $P < 0.05$.

TABLE A2. Heavy/trace metals for wells at Ministik Lake site.

Metal	Casing Material	Well Flushing	Concentration of Specified Metal	
			Filtered	Non Filtered
Ba	Steel	Before	0.065[a]	0.072[a]
	Steel	After	0.167[b]	0.167[b]
	P.V.C.	Before	0.167[b]	0.171[b]
	P.V.C.	After	0.163[b]	0.168[b]
Cd	Steel	Before	0.010	0.010
	Steel	After	0.010	0.010
	P.V.C.	Before	0.010	0.010
	P.V.C.	After	0.010	0.010
Co	Steel	Before	0.010	0.010
	Steel	After	0.010	0.010
	P.V.C.	Before	0.010	0.010
	P.V.C.	After	0.010	0.010
Cr	Steel	Before	0.010	0.010
	Steel	After	0.010	0.010
	P.V.C.	Before	0.010	0.010
	P.V.C.	After	0.012	0.010
Cu	Steel	Before	0.010	0.011
	Steel	After	0.010	0.010
	P.V.C.	Before	0.010	0.010
	P.V.C.	After	0.010	0.010
Fe	Steel	Before	0.815[a]	2.949[b]
	Steel	After	0.228[c]	0.252[c]
	P.V.C.	Before	0.291[c]	0.371[c]
	P.V.C.	After	0.127[d]	0.094[d]
Mn	Steel	Before	0.026[a]	0.037[a]
	Steel	After	0.010[b]	0.010[b]
	P.V.C.	Before	0.012[b]	0.013[b]
	P.V.C.	After	0.012[b]	0.010[b]
Mo	Steel	Before	0.085	0.085
	Steel	After	0.080	0.080
	P.V.C.	Before	0.080	0.081
	P.V.C.	After	0.080	0.080
Ni	Steel	Before	0.010	0.010
	Steel	After	0.010	0.010
	P.V.C.	before	0.010	0.010
	P.V.C.	After	0.010	0.010

... cont'd.

Table A2. (cont'd.)

Metal	Casing Material	Well Flushing	Concentration of Specified Metal	
			Filtered	Non Filtered
Pb	Steel	Before	0.029	0.029
	Steel	After	0.028	0.032
	P.V.C.	Before	0.034	0.031
	P.V.C.	After	0.030	0.031
Sr	Steel	Before	0.071[a]	0.072[a]
	Steel	After	0.102[b]	0.100[b]
	P.V.C.	Before	0.098[b]	0.099[b]
	P.V.C.	After	0.102[b]	0.100[b]
V	Steel	Before	0.030	0.030
	Steel	After	0.030	0.030
	P.V.C.	Before	0.030	0.030
	P.V.C.	After	0.030	0.030
Zn	Steel	Before	0.011	0.016
	Steel	After	0.020	0.016
	P.V.C.	Before	0.028	0.045
	P.V.C.	After	0.013	0.019

Note: 1. Numbers are mean values of concentrations (mg/L) determined during the period, December 1984 - February 1986.
2. Within each metal group, numbers without superscripts (a,b,c,etc.) or numbers with the same superscripts were not significantly different at $P < 0.05$.

Table A3. Routine analysis for wells at Bruderheim site.

Parameter	Casing Material	Before Flushing	After Flushing
pH	Steel	7.59	7.41
	P.V.C.	7.37	7.24
EC	Steel	0.40	0.48
	P.V.C.	0.41	0.45
SAR	Steel	0.61^{a}	0.11^{b}
	P.V.C.	0.13^{b}	0.13^{b}
Ca	Steel	61.62^{a}	92.02^{b}
	P.V.C.	80.02^{b}	86.02^{b}
Mg	Steel	12.66^{a}	16.20^{b}
	P.V.C.	13.36^{a}	14.78^{ab}
T.H.	Steel	205.83^{a}	296.25^{b}
	P.V.C.	254.64^{b}	275.83^{b}
Na	Steel	19.17^{a}	4.22^{b}
	P.V.C.	5.26^{b}	4.98^{b}
K	Steel	2.22^{a}	1.50^{b}
	P.V.C.	1.51^{b}	1.63^{b}
CO_3	Steel	0.00	0.00
	P.V.C.	0.00	0.00
HCO_3	Steel	278.35	345.98
	P.V.C.	300.22	333.47
T.A.	Steel	228.25	283.71
	P.V.C.	246.18	273.45
F	Steel	0.13	0.10
	P.V.C.	0.11	0.10
SO_4	Steel	19.45	18.61
	P.V.C.	17.84	18.41
Cl	Steel	2.51	5.61
	P.V.C.	2.28	2.36
NO_3-N	Steel	0.07	0.07
	P.V.C.	0.07	0.07
NH_4-N	Steel	0.26	0.14
	P.V.C.	0.14	0.12

... cont'd.

Table A3. (cont'd.)

Parameter	Casing Material	Before Flushing	After Flushing
COD	Steel	21.40^{a}	10.00^{b}
	P.V.C.	15.17^{ab}	13.75^{ab}
TDS	Steel	254.88	308.69
	P.V.C.	268.28	292.72

Note: 1. Numbers are mean values of concentrations (mg/L) determined during the period, May 1985 - February 1986.
2. Within each parameter group numbers without superscripts (a,b,c, etc.) or numbers with the same superscripts were not significantly different at $P < 0.05$.

Table A4. Heavy/trace metals for wells at Bruderheim site.

Metal	Casing Material	Well Flushing	Concentration of Specified Metal	
			Filtered	Non Filtered
Ba	Steel	Before	0.521[a]	0.566[a]
	Steel	After	0.814[b]	0.843[b]
	P.V.C.	Before	0.675[b]	0.725[b]
	P.V.C.	After	0.766[b]	0.828[b]
Cd	Steel	Before	0.010	0.010
	Steel	After	0.010	0.010
	P.V.C.	Before	0.010	0.010
	P.V.C.	After	0.010	0.010
Co	Steel	Before	0.010	0.010
	Steel	After	0.010	0.010
	P.V.C.	Before	0.010	0.010
	P.V.C.	After	0.010	0.010
Cr	Steel	Before	0.010	0.010
	Steel	After	0.010	0.010
	P.V.C.	Before	0.010	0.010
	P.V.C.	After	0.010	0.010
Cu	Steel	Before	0.010	0.010
	Steel	After	0.010	0.010
	P.V.C.	Before	0.010	0.010
	P.V.C.	After	0.010	0.010
Fe	Steel	Before	5.143	9.517
	Steel	After	4.937	8.020
	P.V.C.	Before	4.056	6.746
	P.V.C.	After	5.060	8.625
Mn	Steel	Before	0.381	0.404
	Steel	After	0.459	0.467
	P.V.C.	Before	0.510	0.520
	P.V.C.	After	0.433	0.432
Mo	Steel	Before	0.086	0.086
	Steel	After	0.073	0.083
	P.V.C.	Before	0.088	0.088
	P.V.C.	After	0.086	0.090
Ni	Steel	Before	0.012	0.012
	Steel	After	0.010	0.010
	P.V.C.	Before	0.012	0.012
	P.V.C.	After	0.010	0.010

... cont'd.

Table A4. (cont'd.)

Metal	Casing Material	Well Flushing	Concentration of Specified Metal	
			Filtered	Non Filtered
Pb	Steel	Before	0.031	0.039
	Steel	After	0.039	0.038
	P.V.C.	Before	0.036	0.034
	P.V.C.	After	0.034	0.034
Sr	Steel	Before	0.273	0.273
	Steel	After	0.260	0.265
	P.V.C.	Before	0.202	0.205
	P.V.C.	After	0.260	0.250
V	Steel	Before	0.030	0.030
	Steel	After	0.030	0.030
	P.V.C.	Before	0.030	0.030
	P.V.C.	After	0.030	0.030
Zn	Steel	Before	0.013	0.025
	Steel	After	0.013	0.015
	P.V.C.	Before	0.016	0.023
	P.V.C.	After	0.013	0.014

Note: 1. Numbers are mean values of concentrations (mg/L) determined during the period, May 1985 - February 1986.
2. Within each metal group numbers without superscripts (a,b,c, etc.) or numbers with the same superscripts were not significantly different at $P < 0.05$.

TABLE A5. Routine analysis for wells at Botanic Garden site #1.

Parameter	Casing Material	Before Flushing	After Flushing
pH	Steel	7.67	7.89
	P.V.C.	7.12	7.54
EC	Steel	1.25	1.70
	P.V.C.	1.02	1.75
SAR	Steel	3.54	3.54
	P.V.C.	1.87	3.74
Ca	Steel	76.90[a]	150.30[b]
	P.V.C.	88.43[ab]	142.48[b]
Mg	Steel	50.73	72.90
	P.V.C.	44.80	68.57
T.H.	Steel	400.63	675.00
	P.V.C.	405.00	637.67
Na	Steel	171.35	211.60
	P.V.C.	105.23	216.20
K	Steel	4.59	5.86
	P.V.C.	3.03	5.73
CO_3	Steel	6.30	0.00
	P.V.C.	0.00	0.00
HCO_3	Steel	710.88	1177.69
	P.V.C.	634.61	1134.77
T.A.	Steel	593.38	965.70
	P.V.C.	520.38	930.51
F	Steel	0.19	0.16
	P.V.C.	0.48	0.19
SO_4	Steel	169.91	146.49
	P.V.C.	100.86	162.50
Cl	Steel	3.55	3.55
	P.V.C.	3.77	3.55
NO_3-N	Steel	0.07	0.07
	P.V.C.	0.07	0.07
NH_4-N	Steel	1.02	1.33
	P.V.C.	0.77	1.35

... cont'd.

Table A5. (cont'd.)

Parameter	Casing Material	Before Flushing	After Flushing
COD	Steel	61.50[a]	140.00[b]
	P.V.C.	155.00[b]	193.67[b]
TDS	Steel	833.36	1170.43
	P.V.C.	658.65	1157.65

Note: 1. Numbers are mean values of concentrations (mg/L) determined during the period, April 1985 - July 1985.
2. Within each parameter group, numbers without superscripts (a,b,c, etc.) or numbers with the same superscripts were not significantly different at $P < 0.05$.

Table A6. Heavy/trace metals for wells at Botanic Garden site #1.

Metal	Casing Material	Well Flushing	Concentration of Specified Metal	
			Filtered	Non Filtered
Ba	Steel	Before	0.093	0.080
	Steel	After	0.150	0.200
	P.V.C.	Before	0.078	0.090
	P.V.C.	After	0.167	0.350
Cr	Steel	Before	0.010	0.010
	Steel	After	0.010	0.010
	P.V.C.	Before	0.010	0.010
	P.V.C.	After	0.010	0.010
Cu	Steel	Before	0.010	0.010
	Steel	After	0.010	0.060
	P.V.C.	Before	0.010	0.010
	P.V.C.	After	0.010	0.020
Fe	Steel	Before	9.095	9.600
	Steel	After	9.900	12.100
	P.V.C.	Before	5.588	6.432
	P.V.C.	After	10.167	15.200
Mn	Steel	Before	0.148	0.155
	Steel	After	0.100	0.150
	P.V.C.	Before	0.108	0.095
	P.V.C.	After	0.270	0.680
Mo	Steel	Before	0.100	0.100
	Steel	After	0.100	0.100
	P.V.C.	Before	0.083	0.088
	P.V.C.	After	0.083	0.100
Pb	Steel	Before	0.035	0.035
	Steel	After	0.050	0.040
	P.V.C.	Before	0.043	0.048
	P.V.C.	After	0.057	0.050
Sr	Steel	Before	0.768	0.768
	Steel	After	1.270	1.280
	P.V.C.	Before	0.823	0.813
	P.V.C.	After	1.240	1.230
Zn	Steel	Before	0.015	0.015
	Steel	After	0.020	0.030
	P.V.C.	Before	0.037	0.037
	P.V.C.	After	0.037	0.050

Note: 1. Numbers are mean values of concentrations (mg/L) determined during the period, April 1985 - July 1985.
2. Within each metal group, numbers without superscripts (a,b,c, etc.) or numbers with the same superscripts were not significantly different at $P < 0.05$.

Table A7. Routine analysis for wells at Botanic Garden site #2.

Parameter	Casing Material	Before Flushing	After Flushing
pH	Steel	7.86	7.93
	P.V.C.	7.74	7.82
EC	Steel	2.04[a]	1.52[b]
	P.V.C.	1.55[c]	1.56[c]
SAR	Steel	5.44[a]	7.40[b]
	P.V.C.	8.23[c]	8.13[c]
Ca	Steel	156.51[a]	68.64[b]
	P.V.C.	62.46[b]	65.13[b]
Mg	Steel	46.90[a]	24.20[b]
	P.V.C.	22.68[b]	23.08[b]
T.H.	Steel	583.50[a]	270.83[b]
	P.V.C.	249.17[b]	257.50[b]
Na	Steel	298.08[a]	279.45[b]
	P.V.C.	298.23[a]	299.57[a]
K	Steel	5.63[a]	3.98[b]
	P.V.C.	3.78[b]	3.81[b]
CO_3	Steel	0.00	0.00
	P.V.C.	1.90	2.70
HCO_3	Steel	850.62	846.65
	P.V.C.	863.64	872.13
T.A.	Steel	697.51	694.26
	P.V.C.	711.34	719.63
F	Steel	0.15	0.16
	P.V.C.	0.15	0.16
SO_4	Steel	518.72[a]	197.56[b]
	P.V.C.	200.93[b]	199.68[b]
Cl	Steel	3.01	2.66
	P.V.C.	2.36	2.22
NO_3-N	Steel	0.07	0.07
	P.V.C.	0.07	0.07
NH_4-N	Steel	1.09	1.04
	P.V.C.	1.00	1.05

... cont'd.

Table A7. (cont'd.)

Parameter	Casing Material	Before Flushing	After Flushing
COD	Steel	67.50[a]	25.25[b]
	P.V.C.	27.50[b]	18.00[b]
TDS	Steel	1447.67[a]	993.35[b]
	P.V.C.	1017.55[c]	1025.59[c]

Note: 1. Numbers are mean values of concentrations (mg/L) determined during the period, October 1985 - February 1986.

2. Within each parameter group numbers without superscripts (a,b,c, etc.) or numbers with the same superscripts were not significantly different at $P < 0.05$.

Table A8. Heavy/trace metals for wells at Botanic Garden site #2.

Metal	Casing Material	Well Flushing	Concentration of Specified Metal	
			Filtered	Non Filtered
Ba	Steel	Before	0.080	0.100
	Steel	After	0.054	0.050
	P.V.C.	Before	0.060	0.055
	P.V.C.	After	0.052	0.053
Cd	Steel	Before	0.010	0.010
	Steel	After	0.010	0.010
	P.V.C.	Before	0.010	0.010
	P.V.C.	After	0.010	0.010
Co	Steel	Before	0.018[a]	0.020[a]
	Steel	After	0.010[b]	0.012[b]
	P.V.C.	Before	0.010[b]	0.010[b]
	P.V.C.	After	0.012[b]	0.013[b]
Cr	Steel	Before	0.010	0.012
	Steel	After	0.010	0.010
	P.V.C.	Before	0.020	0.012
	P.V.C.	After	0.036	0.010
Cu	Steel	Before	0.010	0.018
	Steel	After	0.010	0.010
	P.V.C.	Before	0.010	0.010
	P.V.C.	After	0.010	0.010
Fe	Steel	Before	17.600[a]	40.517[b]
	Steel	After	4.960[c]	5.422[c]
	P.V.C.	Before	1.483[d]	2.055[d]
	P.V.C.	After	3.080[d]	4.207[cd]
Mn	Steel	Before	0.698[a]	0.740[a]
	Steel	After	0.617[b]	0.615[b]
	P.V.C.	Before	0.757[c]	0.760[c]
	P.V.C.	After	0.758[c]	0.767[c]
Mo	Steel	Before	0.083	0.083
	Steel	After	0.086	0.083
	P.V.C.	Before	0.100	0.100
	P.V.C.	After	0.082	0.100
Ni	Steel	Before	0.025[a]	0.035[a]
	Steel	After	0.014[b]	0.012[b]
	P.V.C.	Before	0.010[b]	0.012[b]
	P.V.C.	After	0.010[b]	0.013[b]

... cont'd.

Table A8. (cont'd.)

Metal	Casing Material	Well Flushing	Concentration of Specified Metal	
			Filtered	Non Filtered
Pb	Steel	Before	0.050[a]	0.078[b]
	Steel	After	0.039[c]	0.042[c]
	P.V.C.	Before	0.032[c]	0.042[c]
	P.V.C.	After	0.034[c]	0.033[c]
Sr	Steel	Before	1.630[a]	1.770[a]
	Steel	After	0.965[b]	0.960[b]
	P.V.C.	Before	N/A	N/A
	P.V.C.	After	N/A	N/A
V	Steel	Before	0.030	0.030
	Steel	After	0.030	0.030
	P.V.C.	Before	0.030	0.030
	P.V.C.	After	0.030	0.030
Zn	Steel	Before	0.455[a]	1.428[a]
	Steel	After	0.029[b]	0.025[b]
	P.V.C.	Before	0.080[b]	0.087[b]
	P.V.C.	After	0.016[b]	0.043[b]

Note: 1. Numbers are mean values of concentrations (mg/L) determined during the period, August 1985 - February 1986.
2. Within each metal group, numbers without superscripts (a,b,c, etc.) or numbers with the same superscripts were not significantly different at $P < 0.05$.

APPENDIX B

HYDROGEOLOGY OF STUDY SITES, WELL CONSTRUCTION AND AQUIFER TEST RESULTS

HYDROGEOLOGY

MINISTIK LAKE SITE

The Ministik Lake site (LSD 14-34-50-21-W4) is located in the southeast segment of the Edmonton map area (NTS 83H) within the Eastern Alberta Plains physiographic region. The site is at the corner of range road 212 and township road 510, approximately 800 m north of North Ministik Lake. The climate is microthermal with long, cool summer days. Precipitation averages 430 mm annually and 75 percent falls as rain (Stein, 1982).

The map area is located entirely within the North Saskatchewan River Drainage Basin. Major elements of the area's topography appear to be bedrock controlled, as the main topographic trend follows the northwest- to southeast-oriented geological strike. A hummocky disintegration moraine caps the study area and gives rise to characteristic undulating to gently rolling knob and kettle topography with numerous irregularly shaped shallow surface water bodies. The maximum elevation is 792 m. Drainage is complex, intermittent and, in places, internal (Stein, 1982).

Glacial deposits overlie a succession of Upper Cretaceous shales, siltstones, sandstones and coals. The drift thickness is about 14 m at the study site. Regional groundwater flow is generally from the study area to the east, but permeability variations and local topographic reversals strongly modify this situation. The site is a local recharge area and local groundwater moves from north to the south toward North Ministik Lake.

Two hydrostratigraphic units are recognized: the Horseshoe Canyon Formation (unit 1), and sand aquifers in the glacial hummocky moraine (unit 2).

Hydrostratigraphic Unit 1

The Upper Cretaceous Horseshoe Canyon Formation consists of feldspathic clayey sandstone, bentonitic mudstone and carbonaceous shale, with scattered coal and bentonite beds of variable thickness (Green, 1972).

The sandstone beds are somewhat hydraulically interconnected by joints and fractures, but the beds are not continuous. The long term well yield from the sandstone is low, due to its bentonitic nature. The coal seams are the most important aquifers in this unit and are capable of producing long term well yields of from 0.4 to 2 L/s (5 to 25 igpm) (Stein, 1979). Local groundwater flow appears to be to the north, with a regional trend to the northeast.

Hydrostratigraphic Unit 2

The aquifers of this unit are lenses of sand and gravel within the hummocky glacial till moraine.

The long term well yield is generally low, however yields of 0.1 to 0.4 L/s (1 to 5 igpm) are possible. Recharge to this unit is primarily from precipitation. Groundwater flow generally follows the topography, flowing from topographic highs to the depressional areas. The flow direction at the well site is to the southeast towards Ministik Lake.

BRUDERHEIM AREA SITE

The Bruderheim study site (LSD 13-30-56-20-W4) is located in the northeast segment of the Edmonton map area (NTS 83H), within the Eastern Alberta Plains physiographic region. The site is on the roadside of Highway 830, about 1 km south of the North Saskatchewan River and approximately 12 km north of the town of Bruderheim. The map area has a microthermal climate with long, cool summer days and receives an average 430 mm of precipitation annually, 70 percent as rain (Stein, 1976)

The map area is located entirely within the North Saskatchewan River Drainage Basin. Major topographic features in the map area follow geological strike directions, e.g., a series of northwest- to southeast-oriented topographic ridges which range from 685 m to 760 m in elevation. This pattern, however, is broken in the study area by the North Saskatchewan River such that the elevation at the study site drops to approximately 610 m (Stein, 1976).

Glacial and postglacial deposits overlie a succession of Upper Cretaceous shales, siltstones, sandstones and coals in the area. The drift thickness at the study site is approximately 48 m, due to the presence of the Beverly preglacial buried valley. This valley trends from the southwest to the northeast, with several tributary valleys joining along its course. The buried valley is incised into the bedrock of the Belly River Formation of Upper Cretaceous age. The study site is in a recharge area, from which groundwater moves vertically downwards toward the buried aquifer and joins the course of the Beverly Channel groundwater flow system.

Three main hydrostratigraphic units are recognized: the Belly River Formation (unit 1), preglacial gravels and sands (unit 2), and aeolian sand and glacio-fluvial outwash sand (unit 3).

Hydrostratigraphic Unit 1

The Belly River Formation consists of non-marine, thick-bedded feldspathic sandstone, clayey siltstone, mudstone and concretionary ironstone beds (Green, 1972).

The regional groundwater flow direction is to the northeast. The aquifer also discharges into the overlying preglacial buried valley gravel and sand deposits. Long term well yield is generally low, due to the bentonitic nature of the sandstone beds. The expected long term well yield is less than 0.1 L/s (1 gpm) at the well site area. The low yield is partially due to the buried valley draining the highest aquifers of this formation in the nearby bedrock.

Hydrostratigraphic Unit 2

Preglacial gravel and sand deposits lie unconformably in the deeply terraced Beverly Valley cut into the upper portion of the bedrock. This is a major buried valley extending from the bedrock uplands, west of Edmonton, through the Cold Lake region and into Saskatchewan (Hatfield buried valley).

The deposit is about 20 m thick at the study site and consists of gravel near the base grading to fine sand and silt to the top.

The direction of groundwater flow in this aquifer is from southwest to northeast. Recharge to the system is from downward seepage of groundwater from the overlying aeolian dune sand aquifer, the upper bedrock aquifers, and from the hydraulically connected North Saskatchewan River. As a result of the connection with the river the upper portion of the aquifer is unsaturated. The expected long term well yield is from 1.9 to 7.6 L/s (25 to 100 gpm) from the coarser material in the lower portion of the channel (Stein, 1976). The overlying finer sands are capbable of long term well yields of 0.4 to 1.9 L/s (5 to 25 gpm).

Hydrostratigraphic Unit 3

This unit is an aeolian dune sand deposit partially derived from underlying glacio-fluvial outwash sand. Both deposits consist of fine to medium grained sand. As both deposits are lithologically similar and hydraulically connected, they are grouped as one hydrostratigraphic unit.

This unconfined aquifer can produce long term well yields from 0.4 to 1.9 L/s (5 to 25 gpm). Groundwater flow is predominantly downward, with some laterial flow discharging along the banks of the North Saskatchewan River and Beaver Hill Creek.

DEVONIAN BOTANIC GARDEN SITE

The botanic Garden site (LSD 13-15-51-26-W4) is located in the southwest quarter of the Edmonton map area (NTS 83H) within the Eastern and Western Alberta Plains physiographic subdivisions. The study site is on the roadside of Highway 60 within the boundary of the Devonian Botanic Garden, which is approximately 10 km north of the Town of Devon. Climate is microthermal with warm summers. Mean annual precipitation is approximately 460 mm and 70 percent of the total precipitation falls as rain (Ceroici, 1979).

The study area is within the North Saskatchewan River Drainage Basin. The topography is largely the result of differential erosion and glacial deposition. The study area is located in the flank of the Stony Valley, with an elevation of approximately 640 m. Recent eolian sand deposits are present in the study area.

The study site is in a recharge area, from which groundwater moves east and south toward the Stony Valley and North Saskatchewan River. The Stony Valley has the lowest hydraulic potential in the area and acts as a "line" sink (Ceroici, 1979). Locally, the site is also in a recharge area from which groundwater moves vertically downwards toward the buried aquifer and joins the course of the buried channel groundwater flow.

Drift thickness at the well site is 59 m, due to the presence of the Stony preglacial buried valley. This buried valley trends from southwest to northeast and is incised into the bedrock of the Wapiti Formation of Upper Cretaceous age.

Clare (1985) has defined four hydrostratigraphic units: Wapiti Formation (unit 1), preglacial sands (unit 2), glacio-fluvial deposits (unit 3) and glacio-lacustrine and aeolian sands (unit 4).

Hydrostratigraphic Unit 1

The Wapiti Formation is, by convention, a combination or grouping of the Horseshoe Canyon and Belly River Formations. The divisional boundary is the North Saskatchewan River to the south and east.

The Wapiti Formation is of non-marine deposition consisting of grey feldspathic clayey sandstone, bentonitic mudstone, bentonite and scattered coal beds (Green, 1972). The permeability of the Wapiti is generally low, mainly due to its bentonitic nature. Although the individual sandstone beds are not continuous, they are interconnected by joints and fractures. The hydraulic conductivity decreases as a result of a decreasing number of joints and fractures and lower porosity of the sandstone beds.

Groundwater flow in this unit is predominately to the northeast. Discharge also occurs to the overlying preglacial sand deposit. Wells may yield up to 0.4 L/s (5 gpm), however, the majority of water wells yield less than 0.1 L/s (1 gpm).

Hydrostratigraphic Unit 2

Preglacial sands lie unconformably in the deeply terraced Stony Valley that cuts into the upper portion of the bedrock. The aquifer is a conduit for a regional flow system from southwest to northeast, joining the main Beverly Valley in the north Edmonton area in the vicinity of the Municipal Airport. Discharge from the Stony Valley

aquifer also occurs at an outcrop along the North Saskatchewan River northeast of the study area, as evidenced by springs and seeps on the present North Saskatchewan River valley wall. The deposit in this area is composed almost entirely of medium sand in the bottom portion grading to very fine sand above. The deposit is 25 m thick at the well site. The medium grained sand in the lower portion will yield from 2 to 8 L/s (26-106 gpm) (the highest quantities of groundwater in the area), while the overlying fine sands will yield from 0.4 to 2.0 L/s (5-26 gpm) (Ceroici, 1979).

Hydrostratigraphic Unit 3

Overlying the preglacial sand is a till, which is present over most of the area. The till has been eroded and dissected by glacial meltwater that deposited glacio-fluvial sediments of hydrostratigraphic unit 3. These sediments consist of gravel, well bedded sands and sandy silts. The aquifer is capable of producing up to 1 L/s (13 gpm) in the most permeable sands of the unit.

Hydrostratigraphic Unit 4

This unit is the combination of two hydraulically connected stratigraphic deposits which are difficult to differentiate, as they have a similar grain size distribution. The lower portion consists of well bedded glaciolacustrine sands, silts and clays from Glacial Lake Edmonton. The overlying aeolian dune sand was derived primarily from the glaciolacustrine sands, which were reworked by wind.

The glaciolacustrine sediments are widespread throughout the area, ranging from 6 to 25 m thick and increasingly coarser from base to top. The upper portion is poorly sorted rhythmically bedded sand and silt, which comprises the thickest portion of the deposit.

The overlying dune sand is presently stabilized by vegetation, except for small blowouts. The dunes reach thicknesses of up to 15 m and are composed of fine grained sand. Between the dunes are aeolian sheet sand deposits.

The aquifer is unconfined, with only the lower portion of the unit saturated with groundwater. A sufficient saturated thickness of clean sand is required to obtain an adequate well yield. Long term well yields vary from 0.04 to 0.4 L/s (0.5 to 5 gpm).

WELL CONSTRUCTION AND AQUIFER TEST RESULTS

MINISTIK LAKE SITE

In November 1984, a test hole was drilled and gamma logged to a depth of 152 m below ground level. Two observation wells were completed in a 2.4 m thick coal seam of hydrostratigraphic unit 1. Both wells were constructed in a similar manner, but with different well casing materials. The wells and test hole were drilled with a rotary drill and the drilling fluid was chlorinated slough water with no additives.

Well #2322E was constructed using 14 cm O.D. steel insert well casing set to 42 m. Well #2323E was constructed with 14 cm PVC well casing set to 46 m. Both casings were bottomed in shale and driven into that material to provide a suitable well seal. The holes were then deepened exposing the coal aquifer.

Well #2322E utilized a 1.5 m length of 7.6 cm I.D., 12-slot (0.30 mm) Johnson stainless steel well screen attached to a 6 m length of 11 cm steel casing. Well #2323E utilized a 1.5 m length of 10 cm I.D. 12-slot (0.30 mm) PVC well screen.

Both wells were bottomed at 49 m below ground level. In well #2322E, a figure K packer was attached to the 11 cm casing and a washdown bottom was on the bottom of the well screen.

Aquifer test data from these wells showed transmissivity value of 2.1 m^2/day (144 igpd/ft), long term well yield of 0.5 L/s (6.7 igpm) and a storativity of 3.05×10^{-4}.

BRUDERHEIM

In March 1985, five observation wells were completed to monitor the hydraulic characteristics in each of the three hystrostratigraphic units. Two of these wells (#2342 and #2343) were installed in hydrostratigraphic unit 3 for this study. Both wells were constructed in a similar manner. Well #2342 was constructed using 8.5 m of 14 cm O.D. steel well casing attached to 1.5 m of 15 cm nominal, 12-slot (0.30 mm), Johnson stainless steel well screen. Well #2343 was constructed of 8.5 m of 14 cm O.D. PVC well casing attached to 1.5 m of 10 cm I.D., 15-slot (0.37 mm) PVC well screen.

The wells were both bottomed at 10 m below ground level. A sand pack of 10-20 seive frac sand was developed adjacent to the well screens. The annulus between the casings and the borehole was sealed with 'Peltonite', a high expansion bentonite.

The deeper wells were constructed of 14 cm O.D steel insert well casing. These wells were not used in this study.

DEVON BOTANIC GARDEN SITE

In February 1985, five observation wells were completed to monitor the hydraulic characteristics in three of the four hydrostratigraphic units. Two of these wells (#2329E and #2330E) were completed in hydrostratigraphic unit 1 (designated as Botanic Garden #1 site). Monitoring of these wells was terminated, after finding that the screens were damaged.

For the continuation of monitoring at this stie, an additional well (#2369E) was completed in October 1985, into stratigraphic Unit #2. Well #2328E was constructed of 14 cm O.D. steel insert well casing set to 24.7 m. Well #2369E was constructed of 18 cm O.D. steel casing set to 16.2 m. The casing of well #2328E was cemented in place and well #2329E was driven and sealed with 'BenSeal'. The wells were then deepened to expose the preglacial
sand deposit. Well #2328E utilized a 1.5 m length of 10 cm I.D., 10-slot (0.25 mm) Johnson stainless steel well screen attached to 25.6 m

of 11 cm O.D. steel casing. Well #2369E utilized a 1.5 m length of 10 cm I.D., 10-slot (0.25 mm) PVC well screen attached to 14 cm O.D. plastic well casing to ground level. Both wells were bottomed at 47.5 m below ground level. An aquifer test on well #2328E was calculated to have a transmissivity of 65.9 m^2/day (4418 igpd/ft) and a long term well yield of 5.0 L/s (66 igpm). Both these wells will be the only wells monitored for this study.

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